

UAB-FT-394  
June 1996

# MAJORANA NEUTRINOS AND LONG RANGE FORCES

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## ABSTRACT

We establish that forces mediated by the exchange of a pair of Majorana neutrinos differ from those due to Dirac neutrino exchange.

Two-neutrino-exchange mediates long range forces between macroscopic objects. This has been recognized for quite a long time now since the pioneering work by Feinberg and Sucher [1], who did the first calculation in the effective Fermi theory for the weak interactions. The result has been rederived later, in the context of the Standard Model to include the neutral current effects, by the same authors [2] and by the authors in reference [3]. The extremely tiny effect generated by the 2-neutrino force is, however, far from the reach of actual experimental check. Indeed, compared to their gravitational attraction, the force between two protons 1 cm apart is about  $10^{-28}$  weaker. Due to the  $r^{-6}$  behavior of this force, it is only at about  $\sim 10$  Å that the gravitational attraction felt by two protons equals in strength the repulsion due to the neutrino mediated force. Clearly, at these distances, neither the gravitational nor the neutrino force can compete with the Van der Waals type forces that provide for the cohesion of matter.

Recently, however, a claim has been raised by Fischbach that 2-neutrino forces could produce catastrophic consequences for compact objects such as white dwarfs or neutron stars [4]. Indeed, many body interactions in dense media, far from being suppressed as compared to the conventional 2-body interactions, would lead to an unacceptably large self-energy for a neutron star. Already 8-body interactions would render a self-energy associated to 2-neutrino exchange forces that exceeds by many orders of magnitude the rest-mass-energy content of the star. Fischbach then proceeds to argue that a mass in excess of 0.4 eV for the neutrino would shorten the range of the interactions to an extent such that the generated self-energy would be kept tolerably small. Of course, should this be true, it has important implications both for particle physics and for cosmology. However, these results have been questioned in recent work by two different groups. In fact, Smirnov and Vissani [5] argue that low energy neutrinos produced and subsequently captured in the core of stars—a phenomenon described in ref. [6]—fill a degenerate Fermi neutrino sea that blocks (Pauli effect) the free propagation of the low frequency neutrinos responsible for the long range force. The second group, Abada *et al* [7], perform the self-energy calculation by a different technique from Fischbach (essentially differing by the way they sum up the N-body interaction effects), and reach the conclusion that it is negligible. From all the above one realizes that the issue is far from being settled and we expect new developments and insights to appear. Here, however, we shall discuss a different aspect of neutrino mediated forces.

In the present work we address the question of long range forces mediated by Majorana neutrinos. Actually, the above referred work has dealt exclusively with Dirac neutrinos and one would like to explore what happens with self-conjugate neutrinos. Majorana neutrinos

fit very naturally in modern particle physics scenarios and it is because of this fact that we feel that a calculation of the explicit form of the 2–neutrino force is relevant. After all, the odds are high that neutrinos are really Majorana particles. And if this is so, all consequences of their nature should be thoroughly explored.

Since Dirac and Majorana neutrinos only differ in the low energy limit and it is the exchange of low frequency neutrinos which is responsible for the large distance potential, we expect a qualitatively different behavior for Majorana mediated forces (through the different symmetry character of the 2–fermion wave–function associated to the indistinguishability of the 2–particle–intermediate state).

The effective 4–fermion lagrangian density can be written –recall that we are interested in the low momentum transfer static source component of the 2–neutrino interaction– as follows

$$\mathcal{L}_{int} = \frac{G_F}{2\sqrt{2}} \bar{\nu}_M \gamma_5 \gamma_\mu \nu_M \bar{n} \gamma^\mu (1 + g_A \gamma_5) n, \quad (1)$$

specialized to the neutron case and where the Majorana neutrino  $\nu_M$  has a mass  $m^1$ . What we essentially need is the Fourier transform of the non relativistic amplitude shown in Fig. 1. Using the dispersion theory approach of ref. [2] the resulting potential can be cast in the form

$$V(r) = \frac{1}{4\pi^2 r} \int_{4m^2}^{\infty} dt \, absM_t e^{-r\sqrt{t}}, \quad (2)$$

where  $absM_t$  stands for the absorptive part of the crossed amplitude ( $t$ –channel) in Fig. 1. It turns out to be

$$absM_t = \frac{G_F^2}{48\pi} t \left(1 - \frac{4m^2}{t}\right)^{3/2}, \quad (3)$$

which displays the  $\beta^3$  behavior characteristic for a  $P$ –wave propagation. The integral in eq. (2) can be given in terms of a modified Bessel function. The resulting potential reads

$$V_M(r) = \frac{G_F^2 m^2}{8\pi^3 r^3} K_2(2mr). \quad (4)$$

For the sake of comparison, we quote the corresponding formulae for a Dirac neutrino. We have

$$absM_t = \frac{G_F^2}{48\pi} t \left(1 - \frac{m^2}{t}\right) \left(1 - \frac{4m^2}{t}\right)^{1/2}, \quad (5)$$

i.e. a  $S$ –wave mode, and the potential (for non–zero Dirac mass)

$$V_D(r) = \frac{G_F^2 m^3}{16\pi^3 r^2} K_3(2mr), \quad (6)$$

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<sup>1</sup>Of course the  $m \neq 0$  requirement is necessary if we want to distinguish physically between Majorana and Dirac neutrinos.

equivalent to the expression given in [4] (setting  $b=1$ , where  $b$  is defined in this reference).

Of course, both potentials coincide when  $m = 0$ , since the distinction between both types of neutrinos is superfluous in this case. They both give

$$V(r) = \frac{G_F^2}{16\pi^3 r^5}, \quad (7)$$

which is the well-known result.

The asymptotic forms of  $K_2$  and  $K_3$  imply that for distances much larger than the Compton wavelength of the neutrino, both potentials exhibit qualitatively different behavior

$$V_M(r) = \frac{G_F^2}{16} \left( \frac{m^3}{\pi^5 r^7} \right)^{1/2} e^{-2mr}, \quad (8)$$

$$V_D(r) = \frac{G_F^2}{32} \left( \frac{m}{\pi r} \right)^{5/2} e^{-2mr}. \quad (9)$$

From equations (4) and (6) we see that for  $m \neq 0$  (and  $r \neq 0$ )  $V_M < V_D$  always. It is apparent that the same will hold true for the case of the N-body forces considered in [4]. Therefore, massive neutrinos, either Dirac or Majorana, will not generate an embarrassingly large self-energy provided  $m > 0.4$  eV, which is the value derived by Fischbach by requiring that no subvolume in the star contains a neutrino exchange energy larger than its own mass. This requirement, although sufficient to prevent the energy problem to arise, might even not be necessary, since the stellar energy crisis may well be fictitious as advocated by [5, 7]. Be it one way or the other, our purpose was quite independent of the self-energy issue, i.e. to display the different character of Majorana mediated long range forces.

We thank the Theoretical Astroparticle Network for support under the EEC Contract No. CHRX-CT93-0120 ( Direction Generale 12 COMA ). This work has been partially supported by the CICYT Research Project Nos. AEN95-0815 and AEN95-0882. R.T. acknowledges a FPI Grant from the Ministerio de Educación y Ciencia (Spain).

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## Figure caption

**Figure 1:** Feynman diagram responsible for the neutron-neutron potential arising from the exchange of two Majorana neutrinos.

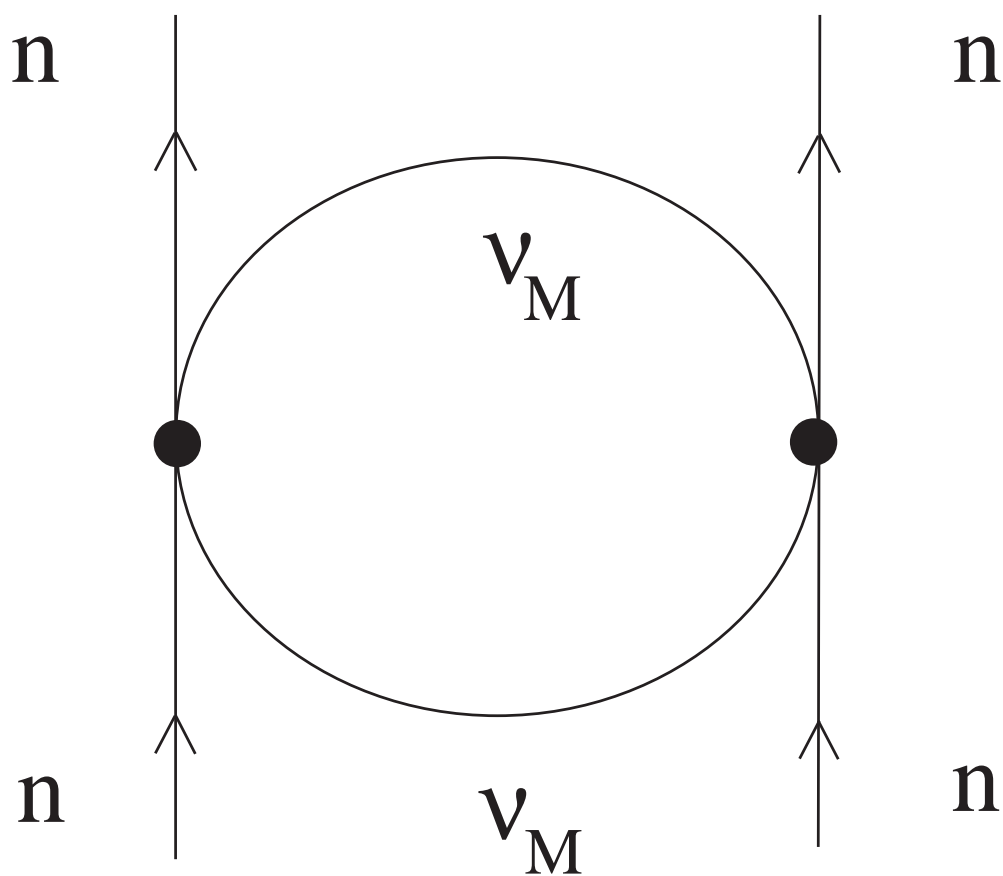


Figure 1